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SPATIO-TEMPORAL EFFECTS OF EL NIÑO EVENTS ON RAINFALL AND MAIZE YIELD IN KENYA

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ABSTRACT

The ability to predict rainfall variability a season in advance could have a major impact on the fragile Kenyan economy. The ability to benefit from climate prediction arises from the intersection of human vulnerability, climate predictability, and decision capacity. Africa may be a prime potential benefactor of seasonal climate forecasting. With this in mind, the link between El Niño-related variability in rainfall at annual and seasonal scales and national-level maize yield in Kenya was explored. The spatial and seasonal variations in El Niño influence on rainfall are highly inconclusive in Kenya except for some highland high rainfall sites and seasons. Significant event-to-event variability was observed, however, during the October–January (OJ) crop growing season during El Niño events. Increases in the OJ seasonal rainfall during El Niño events were reflected in the annual rainfall. While the mean change in rainfall between El Niño and neutral was positive during OJ season and annually, however, the change was negative during the March–June (MJ) season. El Niño effects were greater on rainfall in the second growing season (OJ) for the 1982–83 and 1997–98 El Niño compared with the 1986–87, 1987–88, 1991–92 events. Sites on the highland ecoregion recorded a significant increase in rainfall during El Niño events compared with neutral years. However, the 1987–88 El Niño had a significant effect on the MJ growing season rainfall with consequent positive influence on national maize yield. Furthermore, 'super El Niños' may give rise to larger rainfall responses than normal El Niños at some sites; the magnitude varies from site to site and the effect is not obvious at some sites. The results lead to the conclusion that all El Niños are not equal in terms of their regional manifestation. All this clearly indicates the need to address critical user needs of climate information in order to produce information that is useful. Copyright © 2002 Royal Meteorological Society.

KEY WORDS: El Niño; rainfall; maize; growing season; climate prediction; Kenya

1. INTRODUCTION

Rainfall is a major climatic element in eastern Africa and, therefore, significantly impacts the socio-economic well-being of the population who depend on rain-fed agriculture. The El Niño southern oscillation (ENSO) phenomenon has been linked to climatic variability in many parts of sub-Saharan Africa where unique and persistent anomaly patterns have been detected in the rainfall over parts of southern Africa, eastern Africa, Ethiopia, and the Sahel region during periods of strong and persistent ENSO warm and cold events (Ogallo, 1988; Ropelewski and Halpert, 1987, 1996). With the increasing capability to forecast ENSO events with a lead time of months (Mason, 1998; Philander, 1999) has emerged a growing conviction and interest in using climate information in decision-making processes, especially regarding crop production. Stern and Easterling (1999) have documented evidence of potential and actual uses of climate information in agriculture and water resources. Little of this research has been reported for Africa.

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ENSO events are often characterized as drought years or below-normal rainfall years and above-normal rainfall years. In eastern Africa, El Niños are usually associated with wetter than normal conditions and La Niñas with drier than normal conditions (Ropelewski and Halpert, 1987; Nicholson and Kim, 1997). This has implications for the climatic expectations in such years and the use of climate information in decision making. For agricultural decision making this is especially important. Expectations of El Niño events may result in cultivation of larger areas and higher levels of input use based on expectations of a wet year. Non-realization of such expectations (if the actual event is lower in magnitude than previous events) can lead to considerable losses.

The patterns of impact of El Niños on rainfall have been shown to have specific spatial and temporal variation patterns in eastern and southern Africa, depending on the time and space evolution of each individual ENSO event (Ogallo, 1997); hence the observation that not all El Niños are equal. For example, the 1997–98 event is currently considered the 'super El Niño', and before that it was the 1982–83 event. Additionally, ENSO signals also show variability both within and between events. All these variations affect the use to which climate information based on the prediction of the ENSO events can be put and the level of generalization that can be assumed from one location to another and, subsequently, the response of the users to the information and their continued trust in such information. Although the usefulness of climate information depends on the coping strategies available to the recipients, however, of equal importance is the spatio-temporal accuracy of the relevant information. In order to present climate information in the proper format for the users, there is a need to understand and document how rainfall in different regions within a country varies during different ENSO events in order to provide users with information specific to their local condition and needs (Jagtap *et al*., 2002). This is of particular importance for the application of seasonal climate forecasts in targeting and presenting the information within a time frame consistent with operational requirements and at a spatial scale appropriate to the users' needs (Bohn, 2000).

Kenya has two crop growing seasons related to the rainy seasons: long March–June (MJ; with planting in March to April), and short October–January (OJ; with planting in October to November). The amount of rainfall is greatest in the highlands of western Kenya (Figure 1(a); Table I). The arid lowland of the north and south receives the least amount of rain. Occasionally the rains fail or are below normal for consecutive seasons, leading to drought. Owing to the uneven distribution of rainfall and the variation in land elevation, ecological conditions differ greatly throughout the country. Four main geographic zones were covered in this study: the highland-wet (represented by Kisumu, Kitale, Nakuru, Meru) the lowland-semiarid (Voi, Makindu), the lowland-arid lands (Garissa) and the coastal zone (Malindi), which occupies a narrow strip along the Indian Ocean. The rainfall distributions for a highland site (Kisumu) and lowland site (Makindu) are shown in Figure 1(b) and (c).

A large majority of the people are subsistence farmers who depend on the 20% of Kenya's land that is suitable for producing crops for their own needs. Agricultural production is influenced by the significant spatial and temporal variations that occur in the rainfall (Figure 1(a)–(c) and Table I). In the highlands, continuous cultivation is possible because of high and reliable rainfall (950 to 1340 mm) throughout the year. Since most Kenyans depend on agriculture for a living, it is in these highlands that the majority of the population lives. The largest area of Kenya is arid and semiarid, receiving between 500 and 600 mm of rainfall a year. This amount of rainfall is insufficient for the production of most crops. The coastal zone is a narrow strip of land 16 to 24 km wide along the shores of the Indian Ocean that separates the dry interior from the sea. It is an important crop-producing area because of the relatively heavy rainfall (1000 mm year^{-1}). In the highlands, rainfall during the MJ season is 50 to 100% more than the OJ season and 250% more in the coastal zone. In the lowlands, rainfall during the OJ season exceeds the MJ season by 30 to 100%.

The present study examines sites in agriculturally important zones of Kenya (Figure 1) with a view to addressing the following. (a) Do El Niño events have a discernible effect on Kenyan rainfall? (b) Can El Niño-related rainfall variability be used to explain national-level maize yields using the past 20 years' (1979–98) weather data, which had five El Niño events. Such a synthesis at specific locations, in conjunction with existing climate prediction capabilities, may contribute to the practical utility of climate forecasts for agricultural activities in the region. It is the element of climatic predictability, probabilistic though it is, that

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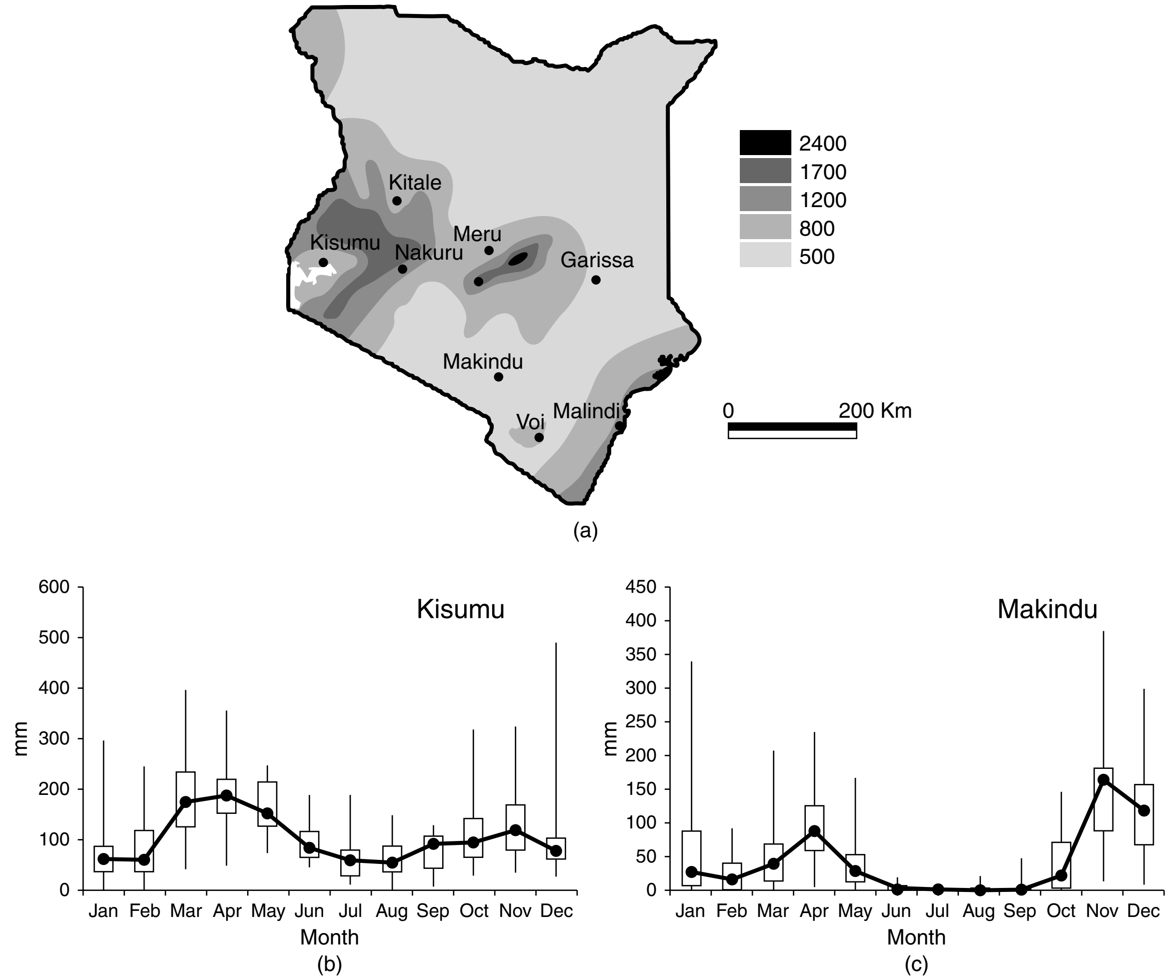

Figure 1. (a) Mean annual rainfall (mm) distribution cross Kenya. Mean annual rainfall at two eco-zones: (b) highland (Kisumu) and (c) lowland (Makindu)

Table I. Geographic descriptions of the study sites along with mean rainfall during the long (MJ), short (OJ) growing seasons and 20 year mean annual rainfall (m ASL: metres above mean sea level)

Site	Latitude (deg)	Longitude (deg)	Altitude (m ASL)	Agroecological zone	Rainfall (mm)		
					MJ	OJ	Annual
Kitale	1.00	35.98	1890	Highland, wet	540	274	1240
Nakuru	−0.27	36.07	1872	Highland, wet	398	254	954
Meru	0.08	37.65	1555	Highland, wet	460	774	1304
Kisumu	−0.10	34.58	1149	Highland, wet	625	431	1340
Makindu	−2.28	37.83	1000	Lowland, semiarid	202	385	619
Voi	−3.40	38.57	560	Lowland, semiarid	208	344	597
Garissa	−0.47	39.63	138	Lowland, arid	198	255	510
Malindi	−3.23	40.10	20	Coastal, wet	621	179	1036

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makes ENSO knowledge potentially useful. Locations with a strong ENSO signal, therefore, may have a type of comparative advantage over areas that do not have such a strong signal.

2. DATA AND METHODS

Several authors have noted that the period after 1979 has seen a tendency towards frequent occurrence of warm El Niño events (Trenberth and Hoar, 1996). Therefore, the present study examined the period from 1979 to 1998 for eight selected sites in Kenya (Figure 1(a)) across various agroecological zones with a view to identifying the spatio-temporal links in rainfall using the five specific El Niño events. The weather data for the present study were obtained from the Kenya Meteorological Department, Nairobi, Kenya. ENSO years were defined on the basis of the Japan Meteorological Agency index (JMA, 1991) during October to September. This index is widely used because it captures many of the well-known El Niño and La Niña events. The JMA index is a 5-month running mean of spatially averaged sea surface temperature anomalies over the tropical Pacific. If the index values equal or exceed $+0.5\,^{\circ}$C for six consecutive months, including October, November, and December, then the anomaly year from October through the following September is considered to be an El Niño event. Accordingly, 1982–83, 1986–87, 1987–88, 1991–92 and 1997–98 were El Niño years. Only one La Niña event (1988–89) was recorded during the period, and thus did not provide enough data points for a similar analysis as that performed for the El Niño events. The remaining 14 years were neutral years.

The rainfall mean and standard deviation (SD) were computed for neutral and El Niño years. At each site, several statistical tests were used to compare rainfall distributions during El Niño and neutral years. To test the hypothesis of equal interannual variability, an F-test was used at the 95% confidence level. An independent t-test was used to test the hypothesis of identical arithmetic means using both the assumption of equality (EV) and unequality (UV) of variances. For each test, p-values are provided.

Maize is the dominant crop in Kenya and is a major household staple. Maize was used in this study to illustrate the influence of ENSO-related rainfall variability on crop production. Although the emphasis here is on maize, the production of a number of crops (such as millet, sorghum, and beans) planted at about the same time as maize will also be affected by ENSO, but impacts of climatic variability related to ENSO would differ depending on the phase and the crop. Time series of annual maize yield (kg ha^{-1}) in Kenya were derived from the FAOSTAT database (FAO, 1990–98). Annual yield data are an aggregation of countrywide annual crop production. A polynomial trend line for estimated maize yield was fitted to remove temporal trends in yield related to factors other than climate (such as technological improvements), using SAS (SAS, 1995). To elucidate the impact of El Niño and non-El Niño years on annual maize yield, residuals were analysed with respect to El Niño and neutral years. Change in maize yield (YC) was calculated as:

$$\mathrm{YC} = (P_x - P_{x-1}) \times 100/P_{x-1}$$

where YC is the change in yield from the previous year, P_x is the yield in year x, and $x - 1$ is the yield in the previous year before year x.

3. RESULTS

3.1. Annual and seasonal rainfall: El Niño versus neutral

Rainfall statistics during 14 neutral years and five El Niño years are compared in Table II. Mean change (El Niño − neutral) in annual rainfall was positive for all sites except Malindi. On average, annual rainfall increased by 72 mm during El Niño events compared with neutral years. This positive change was significant ($\rho \leq 0.05$) at Nakuru. Mean year-to-year annual rainfall variability (SD) was higher (378 mm) during El Niño years compared with neutral years (222 mm). The variability in annual rainfall between El Niño event years was significant ($\rho \leq 0.05$) at Meru, Makindu, and Voi, and at Malindi ($\rho \leq 0.10$). Kitale, Nakuru, Meru,

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Table II. Annual and seasonal rainfall characteristics at the study sites in Kenya[a]

	Highland				Lowland				Average
	Kitale	Nakuru	Meru	Kisumu	Makindu	Voi	Garissa	Malindi	
Annual rainfall									
Mean									
neutral	1219	885	1297	1313	589	593	511	1034	930
El Niño	1264	1115	1375	1425	657	633	521	1027	1002
change	45	230	78	112	68	40	9	−7	72
SD									
neutral	152	180	364	202	175	175	304	224	222
El Niño	191	157	828	331	357	352	390	418	378
p-value									
F-test	0.49	0.85	**0.02**	0.17	**0.05**	**0.05**	0.45	**0.08**	
t-test UV	0.33	**0.01**	0.42	0.26	0.35	**0.41**	0.48	0.49	
t-test EV	0.32	**0.01**	0.44	0.16	0.37	0.43	0.39	0.47	
MJ rainfall									
Mean									
neutral	550	410	486	656	186	211	199	656	419
El Niño	491	379	438	544	193	192	181	542	370
change	−59	−30	−48	−112	7	−19	−18	−113	−49
SD									
neutral	125	142	191	153	102	124	138	240	152
El Niño	69	171	69	142	108	61	92	110	103
p-value									
F-test	0.27	0.55	***0.06***	0.96	0.78	0.18	0.46	0.14	
t-test UV	0.11	0.37	0.22	***0.09***	0.45	0.33	0.38	***0.10***	
t-test EV	0.20	0.35	0.28	0.12	0.38	0.36	0.48	0.23	
OJ rainfall									
Mean									
neutral	255	206	754	378	369	338	247	158	338
El Niño	305	403	844	626	434	377	297	241	441
change	50	197	90	248	65	39	50	83	103
SD									
neutral	110	89	288	108	165	159	150	89	145
El Niño	138	189	764	292	300	228	383	376	334
p-value									
F-test	0.49	**0.04**	**0.01**	**0.01**	***0.10***	0.30	**0.01**	**0.00**	
t-test UV	0.25	**0.04**	0.40	***0.07***	0.33	0.37	0.39	0.32	
t-test EV	0.23	**0.01**	0.39	**0.01**	0.39	0.42	0.31	0.26	

[a] Within the 1979–98 period, El Niño years were 1982–83, 1986–87, 1987–88, 1991–92, and 1997–98; a La Niña year (1988–89) and the remaining 14 years were neutral years. Numbers in bold are significant at $\rho \leq 0.05$ and bold italic numbers at $\rho \leq 0.10$.

and Kisumu are higher elevations (>1000 m, Table I) sites. The mean annual rainfall during the neutral years at the four highland sites was 1180 mm, compared with 680 mm at the four lowland sites (Figure 2). During the five El Niño event years, mean rainfall at the highland sites increased by about 115 mm compared with 30 mm at the lowland sites. Nakuru, the only site with a significant positive annual rainfall change (El Niño – neutral) is a highland site. Of the four sites that showed significant variability in annual rainfall between El Niño event years, three sites — Makindu, Voi, and Malindi — are lowland (<1000 m) sites, whereas the fourth site, Meru, is in the highlands. Compared with the other seven sites, the Meru highland site had the highest rainfall variability (828 mm) between El Niño events. This variability was more than twice

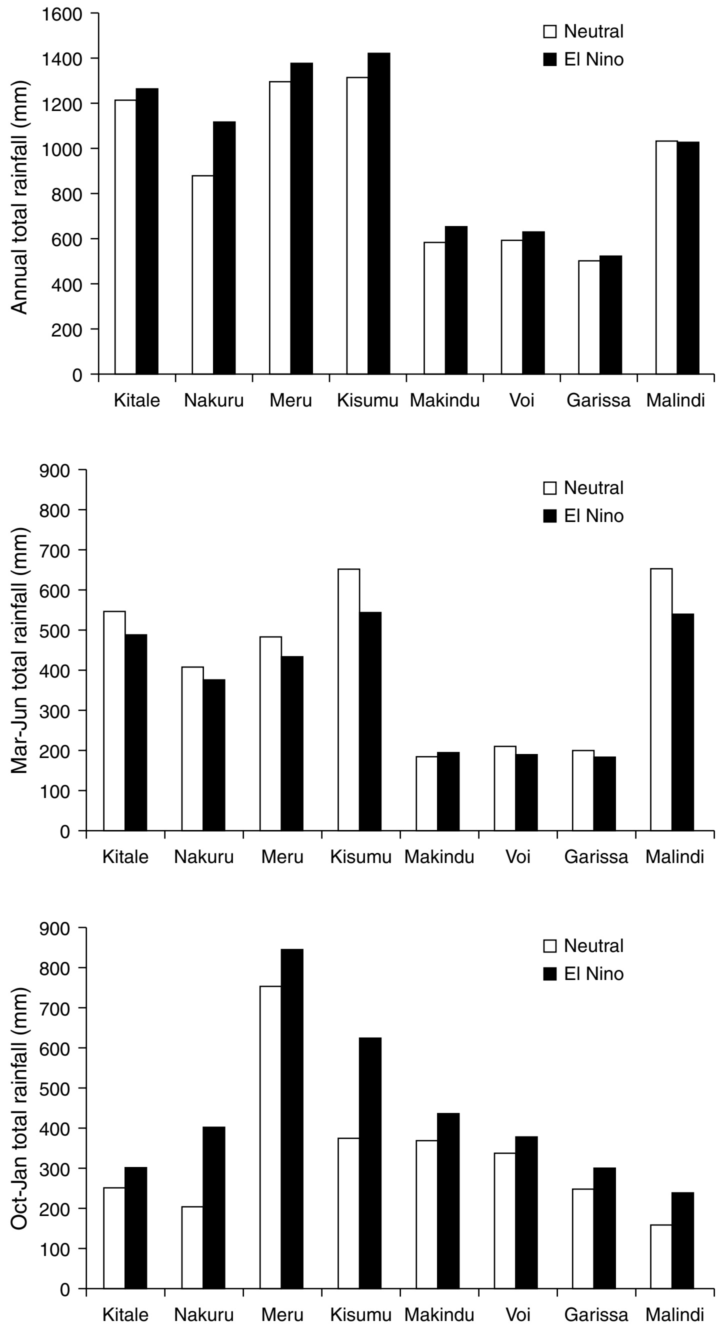

Figure 2. Annual and seasonal variations in rainfall during neutral and El Niño years at the eight study sites in Kenya

the mean variability for the same site between the neutral years. Garissa and Malindi in the lowland–arid ecoregion showed the least difference in mean annual rainfall between El Niño and neutral years.

Mean OJ seasonal rainfall change (103 mm) between El Niño event years and neutral years was positive across sites. This positive change was significant ($\rho \leq 0.05$) at Nakuru (+197 mm) and Kisumu (248 mm). There was a higher OJ seasonal rainfall variability between El Niño event years (mean SD = 334 mm) compared with the variability between neutral years (mean SD = 145 mm). The event-to-event seasonal

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rainfall variability between El Niño years was significant ($\rho \leq 0.05$) at Nakuru, Meru, Kisumu, Garissa, Malindi, and at Makindu ($\rho \leq 0.10$). Most of the sites that showed significant variability in annual rainfall between El Niño event years also had a similar trend in annual rainfall during the OJ season.

In contrast to the pattern observed for the annual and OJ seasonal rainfall, the mean change in MJ seasonal rainfall between El Niño and neutral years was negative (−49 mm) across sites except at Makindu. Sites in the highland wet ecoregion observed the greatest decrease (−112 mm) whereas the lowland arid/semiarid low rainfall sites had the smallest decrease (<20 mm) in rainfall. The negative rainfall change was significant ($\rho \leq 0.10$) at Kisumu (highland wet; −112 mm) and Malindi (coastal wet; −113 mm). Mean MJ seasonal rainfall variability between El Niño events' years (103 mm) was lower than between neutral years (152 mm). The variability in seasonal rainfall between El Niño event years was significant ($\rho \leq 0.10$) at Meru.

This analysis reveals that, except at Nakuru (annually and OJ season) and Kisumu (OJ season), there is not enough evidence of a clear El Niño signal to be able to make any generalized recommendations of either positive or negative rainfall enhancement during an El Niño year compared with neutral years using seasonal rainfall analysis. However, the same analysis showed a significant increase in rainfall variability (SD) between El Niño events in both ecoregions (highland and lowland) during OJ. At Meru, variability was generally higher during El Niño events, irrespective of growing seasons.

3.2. *ENSO signal: comparison of five El Niño events*

Considerable year-to-year and site-to-site variations exist in rainfall during El Niño event years compared with the mean of neutral year rainfall (Table III). Among El Niño years, 1982–83 and 1997–98 events were unique compared with the other three events in terms of rainfall changes (Table III) from neutral years. Of the five El Niño event years, 1997–98 had the highest positive change from mean annual rainfall recorded in neutral years and OJ seasonal rainfall. During the 1997–98 El Niño event, all sites recorded an average

Table III. Difference in rainfall during El Niño years compared with mean rainfall during 14 neutral years and the number of El Niño years that had rainfall higher (positive) and lower (negative) than mean neutral year rainfall

	Rainfall difference (mm)								
	Kitale	Nakuru	Meru	Kisumu	Makindu	Voi	Garissa	Malindi	Average
Annual Rainfall (mm)									
1982	236	158	23	−343	145	−74	−155	−54	−8
1986	−139	214	−430	457	−74	92	−229	−43	−19
1987	47	290	−428	177	−107	−181	−244	−284	−91
1991	−155	33	−295	−98	−273	−260	−12	−354	−177
1997	235	454	1522	366	648	623	688	698	654
Positive change	3	5	2	3	2	2	1	1	*2*
MJ									
1982	−21	−218	−63	−352	−153	−96	−120	−83	−138
1986	42	−104	−106	−71	−21	14	−101	−129	−59
1987	−95	221	61	23	89	−39	15	−191	*11*
1991	−132	−106	−104	−97	−3	−40	103	−222	−75
1997	−90	54	−28	−63	123	64	14	57	17
Negative change	4	3	4	4	3	3	2	4	*3*
OJ									
1982	186	204	42	67	291	24	14	4	104
1986	−99	388	−281	498	−22	97	−70	−104	51
1987	7	−5	−541	160	−167	−139	−212	−114	−126
1991	−49	19	−172	−87	−238	−180	−196	−121	−128
1997	204	379	1404	603	461	393	715	750	614
Positive change	3	4	2	4	2	3	2	2	*3*

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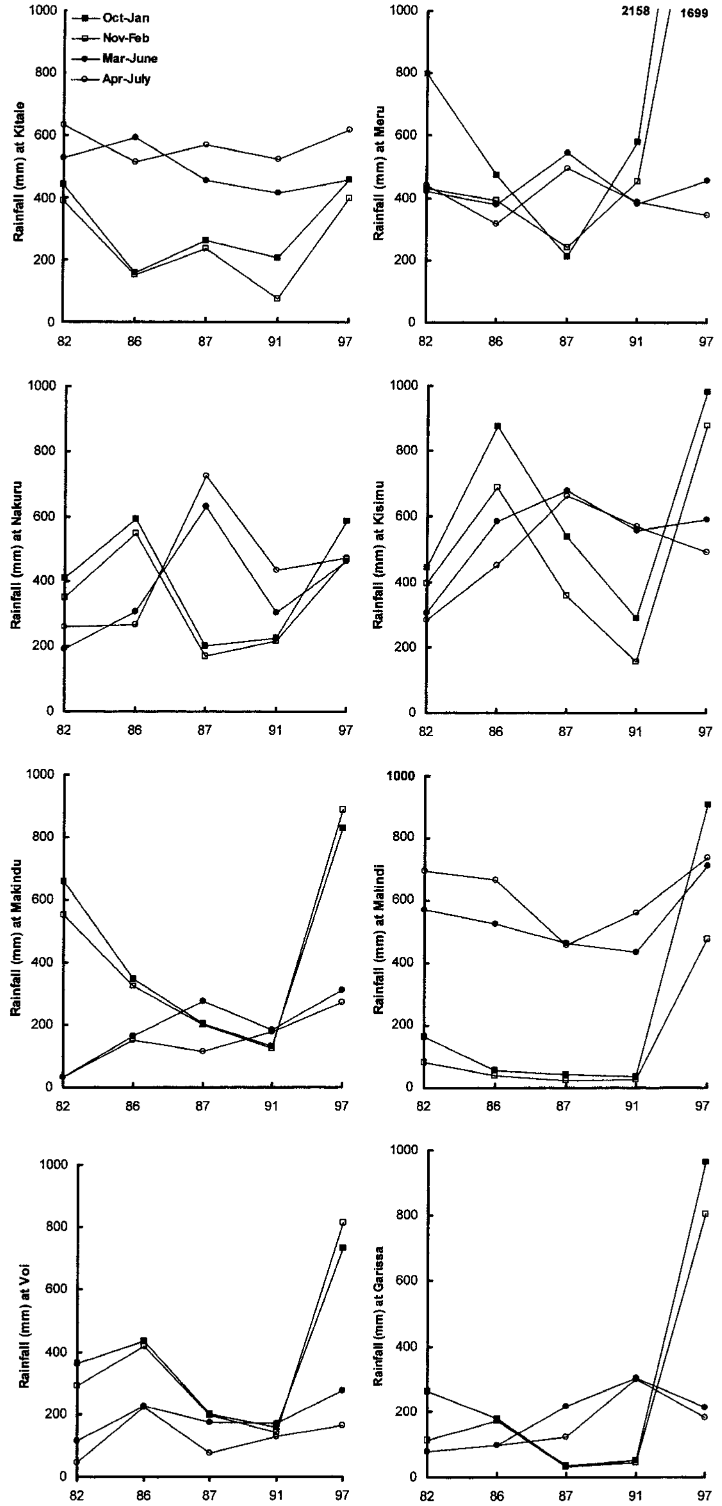

Figure 3. Four planting dates and seasonal rainfall pattern during five El Niño events at eight locations

annual increase of 654 mm (range 234–1522 mm) of rain compared with neutral years' mean (Table II). The increase during the same event in the MJ season was 17 mm (range −90 to 123 mm) and in the OJ season it was 614 mm (range 204–1404 mm). By contrast the signal during the 1982–83 was mixed, but clearly showed an annual (−8 mm) and MJ (−138 mm) seasonal rainfall decline (Table III). Additionally, there were considerable site-to-site variations, as seen in Table III and Figure 3. Generally, highland sites have a strong El Niño signal showing a higher number of years with negative and positive changes in El Niño rainfall, compared with lowland sites. Across the eight sites, at least two years out of the five El Niño event years had annual rainfall above the mean annual neutral years' rainfall. At least three out of the five El Niño years had OJ seasonal rainfall above the neutral years' mean, whereas the converse was the case for MJ seasonal rainfall with three out of the five event years recording below mean neutral year rainfall. Also, it seemed that 'super El Niños' might give rise to larger rainfall responses than normal El Niños at some sites. However, the magnitude will vary from site to site and the effect may not be apparent at some sites (Figure 3). This clearly calls for site-specific El Niño rainfall advice.

As shown in Figure 3, during the 1987–88 event several sites exhibited a rainfall trend that was uniquely different from an El Niño rainfall trend. Nakuru, Meru, Makindu, and Garissa had positive MJ seasonal rainfall change from neutral year mean seasonal rainfall, although the preceding OJ seasonal rainfall change was negative. If this could be predicted, this could imply that expectations of better MJ seasons following less than normal preceding October–November seasons could be capitalized on. Farmers could then be encouraged either to increase the area planted to most crops or to plant less stress-tolerant crops, thus making up for possible shortfalls in grain production from the previous season.

In Kenya, crop plantings start in March or April for the long rains and October or November for the short rains season, thus making it possible to have an MJ or April–July (AJ) and OJ or November–February (NF) planting seasons depending on the onset of the rains. In addition to the total seasonal rainfall, the temporal distribution of rainfall during the growing season, and particularly at the critical growth stages (silking for maize, for instance), may result in a variety of yield–rainfall responses. Therefore, in addition to the MJ and OJ growing seasons, we also looked at the implications of El Niño events on the two later seasons of AJ and NF. The 1997–98 El Niño was certainly larger in terms of the significant amount of rainfall received for the OJ and NF seasons at Malindi, Voi, Makindu, Garissa, Meru, and Kisumu than those of 1982–83, 1986–87, 1987–88, and 1991–92. However, the growing-season rainfall patterns for these five El Niño events were not altogether consistent. At Nakuru, total rainfall received in the OJ (594 mm) and NF (500 mm) planting seasons for the 1997–98 event was similar to that of 1986–87. Similarly at Kitale, the 1997–98 and 1982–83 total rainfall was similar during the two events for the OJ (459 mm) and NF (400 mm) planting seasons. In general, rainfall during the MJ and/or AJ planting seasons at Voi, Malindi, and Kitale appears to follow a similar trend to the OJ and NF plantings for the five events, whereas trends follow different directions at Nakuru, Kisumu, Makindu, and Garissa, such that for those events in which the OJ and NF has a higher rainfall amount, MJ/AJ has a lower rainfall amount. The 1987–88 and 1991–92 events appeared to have led to a smaller response in terms of total rainfall received during the OJ and NF seasons, while the 1987–88 event also appeared to have had the greatest response during the MJ and AJ planting seasons at most locations. It is thus possible to conclude that 'big El Niños' may give rise to larger rainfall responses than normal El Niños at some sites.

3.3. *Maize yield*

In Kenya, the crop production cycle is well synchronized to the ENSO year (October of previous year to September of following year). There are two growing seasons: one starts in October with harvest in the following year and the other in March with harvest in the same year. The year-to-year variations in national average maize yield shown in Figure 4 for Kenya from 1979 to 1998 (FAO, 1990–98) indicate that maize yield increased in the 1980s from 1.5 t ha^{-1} and stabilized at 1.7 t ha^{-1}. Among the five El Niño events (filled symbols), the 1982–83 and 1986–87 events were associated with maize yields above the trend line (+0.10 to +0.12 t ha^{-1}) whereas other events were below the trend line by about 0.04 t ha^{-1}. Except for the 1982–83 and 1986–87 events, the other three El Niño years showed a positive maize yield change of

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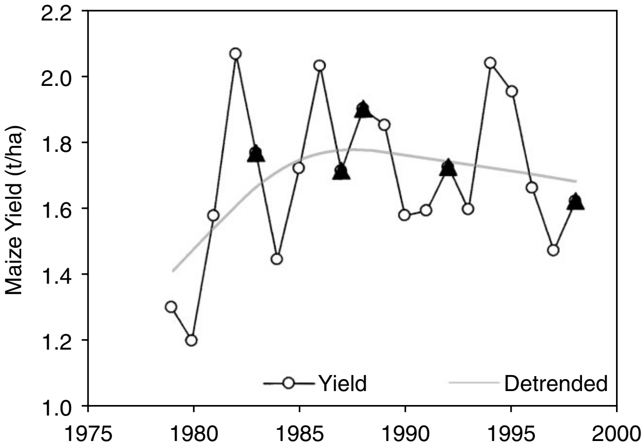

Figure 4. Annual maize yield trend for the period 1979–98. Filled squares represent El Niño years

0.13 to 0.19 t ha^{-1} compared with the preceding non-El Niño years. From this, it is not possible to conclude why El Niño years are associated with positive or negative changes in maize yields. However, the highest yielding years in the time series were non-El Niño years. The 1997–98 'super event' corresponded with the lowest yield level for all five El Niño events. This is likely to suggest that widespread losses (due to excess rainwater) of crops and nutrient applied to maize may be responsible for low yields in spite of apparent high rainfall during El Niño years. Production of a number of crops could also be affected by rainfall variability related to El Niño, since the growing period for these crops is similar to that of maize. However, the impact of El Niño on individual crops will depend on the physiology and management of each crop.

4. DISCUSSION AND CONCLUSIONS

Environmental variation in Kenya follows footprints of climatic differences, defined largely by rainfall, which is highly seasonal as well as variable from year to year. Most cultures in Africa employ only rudimentary, nonscientific means of predicting and responding to large fluctuations in rainfall. In this region, forecasts of the onset and duration of rains in Kenya could be significantly improved by linking them to global phenomena such as ENSO, and may contribute to developmental efforts. Many different interventions have been tried across the continent with varying degrees of success (Ogallo, 1997, 1998; Mutai and Ward 2000) to investigate these relationships. Our analysis using the most recent data from agriculturally important regions of Kenya showed that such relationships can be discerned in some areas or years, but that in other years or places, for some inexplicable reasons, the relationships fail to hold. Such relationships, therefore, must obviously be investigated further, so as to provide a reliable means of predicting future climate patterns.

Rainfall in Kenya varies dramatically between the extreme humidity of highland areas, where average annual rainfall values of around 1200 mm are common, to the driest areas towards south, where 500 mm per year is typical. Reliability of annual rainfall also decreases considerably as one moves further to the south, where the rains become less reliable. In highland areas, variation may be 20% above or below the average, whereas in lowland semiarid regions the rainfall can be as much as 60% above or below the norm.

Spatial analysis of rainfall data in various agroecological zones of Kenya indicates the existence of some spatial coherence and, to a lesser extent, a teleconnection in the distribution of rainfall. Such a teleconnection may be time lagged, positive or negative. Examples of such teleconnections include the relationship of El Niño to rainfall in the highlands and the relationship of rainfall variability in the lowlands. Differences in rainfall during El Niño and neutral years were more evident at the seasonal scale than the annual scale. Similarly, mean rainfall variability was higher in El Niño years, with significant variability at Meru, Makindu, Voi, and Malindi. The OJ season clearly displayed considerably significant rainfall variability during El Niño event

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years at most sites. Significant positive OJ rainfall change from neutral mean rainfall was observed at highland sites. For the MJ season, a negative rainfall change from the neutral year mean rainfall was observed during El Niño events for most sites. Although this analysis supports the earlier findings that El Niños enhance eastern and southern Africa rainfall (Ogallo, 1997, 1998; Mutai and Ward 2000), there is considerable spatial and temporal variability preventing one from drawing conclusive general guidelines.

At the national level, the year-to-year variability in the rainfall was reflected in the maize yields, which have followed the rainfall trend. However, this is not true during the crop growing seasons, and does not translate into higher yield. The negative change from mean neutral years seasonal rainfall during El Niño years for the MJ season, when 65% of maize is produced, may explain the lower national-level yields observed during most El Niño event years. There appear to be some clear signals between the OJ seasonal rainfall and El Niño in Kenya, particularly in the highlands, where significant positive increases were observed. Across most sites, significant variability was observed in the El Niño event years' OJ seasonal rainfall. However, since the bulk of the maize produced in this region is obtained during the March/April season, the additional rainfall during the OJ seasons is more or less underutilized. There may, therefore, be a need to encourage farmers to take more advantage of the October/November season during El Niño years, either to increase the area devoted to maize or to adopt the planting of the crop during this season if they do not already do so.

El Niños have been shown to enhance eastern African rainfall in October–December and May (Mutai and Ward, 2000). However, the same is not true for the MJ season. The enhanced intensity and spatial spread of the 1987–88 El Niño event in the March–May season make it unique and may explain the higher maize productivity observed in that year. Of the five El Niño events (two super and three milder), one of the super events had a yield level within the range for the milder events and the other a yield level less than the range for the milder events. Thus, the present study cannot conclude that higher yield levels are obtained during milder events than the super events, although the highest yield level of the five events occurred during 1987–88 (a milder event). Du Toit and Prinsloo (2001) observed that, in South Africa, milder events were associated with higher national level maize yields compared with the stronger or super events. It has been observed (Allan and Haylock, 1993; Suppiah, 1996) that the relationship between rainfall and ENSO is unstable and changing over time, and so is the relationship between El Niño events and crop production (Kirono and Tapper, 1999). The present study also indicates significant event to event variability in rainfall during the OJ season at most sites. Further research is needed to examine the 1987–88 event, vis-à-vis the others, to determine the characteristics that set it apart and also on the agricultural effect of El Niño events differentiated by strength. We are currently using a crop simulation approach to examine how the five different El Niños affected different growth stages of maize at all the sites with the objective of identifying the reasons for the yield variations observed during the different events.

The improving capability to forecast ENSO events (Mason, 1998) has led to a growing awareness and interest in practical utility of incorporating climate information into the agricultural decision-making process by small-scale farmers in Africa. Climate forecasting is a promising technology currently being targeted at farmers in developing countries to help in mitigating climatic risks to crop production. It has been suggested that the greatest benefit of application of climate forecasting will be derived in vulnerable developing countries, such as those in Africa (Stern and Easterling, 1999).

The results presented here lead to the conclusion that all El Niños are not equal in terms of their regional impact on Kenyan rainfall. The potential application of El Niño-related information will also result in a wide range of responses. Thus, our results indicate the need to address critical user needs of climate information in order to produce information that is useful. The present capability with regard to climate forecasts provides information only on what type of event to expect (El Niño, La Niña), and indicates, to some extent, the intensity of the event as indicated by the Southern Oscillation index (SOI) and other indices. The present research points to the need to go further than this. There is a need to enhance our capability to assess the impact of El Niños on the different growing seasons (long, short), and to develop a methodology to grade El Niños not only in terms of their intensity as measured by the SOI (and other indices) but also in terms of the effect on the total and the distribution of seasonal rainfall. Several climate outlook forums organized in various parts of Africa have suggested such a course of action. Achieving this will require continuing analyses.

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